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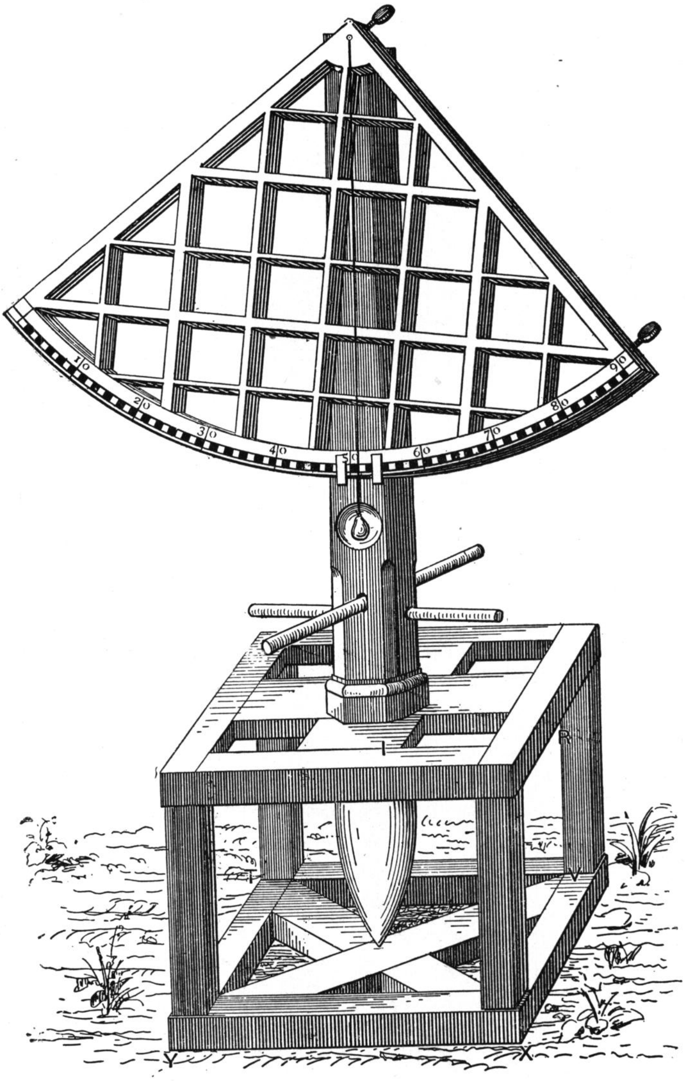

TYCHO BRAHE'S OUTDOOR QUADRANT.

(SEE PAGE 139.)

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THE RISE AND PROGRESS OF ASTRONOMY IN CENTRAL EUROPE.—II.

BY SIDNEY D. TOWNLEY.

The work of COPERNICUS, after his death, was taken up by ERASMUS REINHOLD (1511 to 1553), professor of mathematics at Wittenberg, who checked and corrected all the calculations of COPERNICUS, and computed a new set of tables, known as the Prutenic tables. These were published in 1551; and as they gave the positions of the heavenly bodies more accurately, they soon displaced the ancient Alphonsine tables.

The next great name in the astronomy of Central Europe is that of TYCHO BRAHE. The life of this strange and wonderful man has been written many times. His work, however, was epoch-making in the history of practical astronomy, and cannot be passed over hurriedly.

TYCHO BRAHE (1546 to 1600), eldest son of a Danish nobleman, was born at Kundstrup, in the southern part of the Scandinavian peninsula, then a portion of Denmark. He studied law at the universities of Copenhagen and Leipsic, but became interested in astronomy through observing a predicted eclipse of the Sun, August 21, 1560. It was the prediction more than the eclipse that interested him. Even at that early age he was struck with wonder at the power of a science by which such events could be accurately foretold. From that time on much of his attention was given to the study of astronomy.

For several years after leaving Leipsic TYCHO lived an undecided life, his time being divided between Germany and his native country, his studies between astronomy and alchemy. His attention was finally fixed upon astronomy by the appearance of the new star in 1572. His work upon this attracted much notice and brought him fame. In 1576, King FREDERICK II. gave him an estate, a pension, and one hundred thousand dollars to build and equip an observatory on the island of Hveen, situated fourteen miles to the northeast of Copenhagen. This observatory was equipped with by far the finest instruments ever constructed up to that time. Here TYCHO labored for twenty years, and reared for himself a lasting monument in the great number of magnificent and accurate observations there made. TYCHO was no respecter of persons, however, and although the most eminent man of science in Europe, yet he made many enemies, and when King FREDERICK died TYCHO left Denmark after five years of persecution. With his family and instruments, he went back to Germany, and finally settled in Prague, where Emperor RUDOLPH II. gave him a castle. Here little was done, however; for in a few years TYCHO died, at the age of fifty-four years.

Thus, in brief, is an outline of TYCHO BRAHE'S life. Many of its details have been preserved; and as he was in many respects a peculiar man,— we might almost say eccentric,— some of the details are very interesting. It is my purpose, however, to deal with his contributions to science rather than with personal incidents.

TYCHO'S observations were commenced during his student days at Leipsic. His first instrument was a pair of compasses. By holding these near the eye and pointing one leg at a star and the other at a planet, he was able to obtain the angular distance between the two bodies; and by measuring the angular distance of the planet from two or more known stars, he could determine the position of the planet. Even with such a crude instrument he was able to ascertain that the positions of the planets were not well represented by either the Alphonsine or the Prutenic tables, TYCHO'S first recorded observation was made, 1563, August 17.

The next instrument used by TYCHO was a cross-staff. Two straight, graduated pieces of wood were placed at right angles to each other, the shorter one movable upon the longer. A fixed sight was placed at the right angle and a movable sight on the shorter arm. The method of using the instrument was as follows: The shorter arm was first set at an arbitrary mark on the longer arm; then, holding the instrument in the plane passing through the two bodies and the observer's eye, the eye being at the end of the longer arm, the observer sighted along the longer arm and through the fixed sight at one body and from the end of the longer arm through the movable sight, or along the hypotenuse of the right-angled triangle, to the second body. The graduation on the arms gives the base and perpendicular of a right-angled triangle; and it is, of course, a simple problem to compute the angle at the eye or the angle between the two bodies. It is easy enough to see that such an instrument is a very crude affair. Still TYCHO soon discovered that the divisions upon his did not give the angles correctly. Not being able to obtain the money to purchase a new one, he set to work to construct a table of corrections, to be applied to the readings of his instrument to give the true angles. This point is worthy of emphasis, as I believe it was the first time such a thing had been done. Ancient observers had always considered their instruments perfect, and had taken without question the results given by them. Now, one of the most important steps in astronomical observations is to determine the instrumental errors, and to make allowance for them in deducing the results.

TYCHO did not enter seriously into the business of observing before the observatory was built on the island of Hveen. Some scattering observations were made at home in Denmark, and at different places in Germany. At Augsburg he constructed a huge quadrant, a cut of which is shown in frontispiece.* It was a massive affair, made of oak, with an arc of brass. The radius of the circle was fourteen cubits, or about nineteen feet. The manner of using it is evident from the cut. It stood in the open air, but was unfortunately destroyed by a storm after a short life of five years.

Another instrument designed by TYCHO, and used in his earlier observations, was a sextant. This consisted simply of two arms of wood about five and one half feet long, joined together with a hinge at one end and connected near the other by an arc of 30°. A sight was placed upon each arm.

After giving his attention for some time to studies of a chemical and medical nature, TYCHO'S energies were finally turned for good to the science of astronomy by the appearance of the new star in *Cassiopeiæ* in 1572. This was the first phenomenon of this nature recorded since the time of HIPPARCHUS. The star was already of great brilliance before it was noticed by TYCHO. The observations taken were in some respects different from those now made on a new star. Such phenomena were, of course, very imperfectly understood. Many supposed the new star to be a comet without a tail, and comets were then thought to be effusions in the Earth's atmosphere. Of all those who concerned themselves with this new star, TYCHO seems to have been about the only one to approach the matter in a scientific way. He saw that a few well-directed observations would be worth more than all the theories the human brain could concoct. He not only observed the changes in brightness and color of the star, but carefully measured, with a sextant, during the several months it remained visible, its distance from the principal stars of *Cassiopeiæ*. These distances did not change, thus showing the body to be neither of a planetary nor cometary nature. He also observed its distance from *Schedir* at upper and lower culmination, to detect if possible any parallax. Of course, none was found, thus showing that the body was not in the sphere of the Moon. It also twinkled like other stars, and TYCHO'S conclusion was that it belonged to the eighth sphere, or the sphere of the fixed stars. TYCHO drew up a manuscript of his observations and conclusions, and after much

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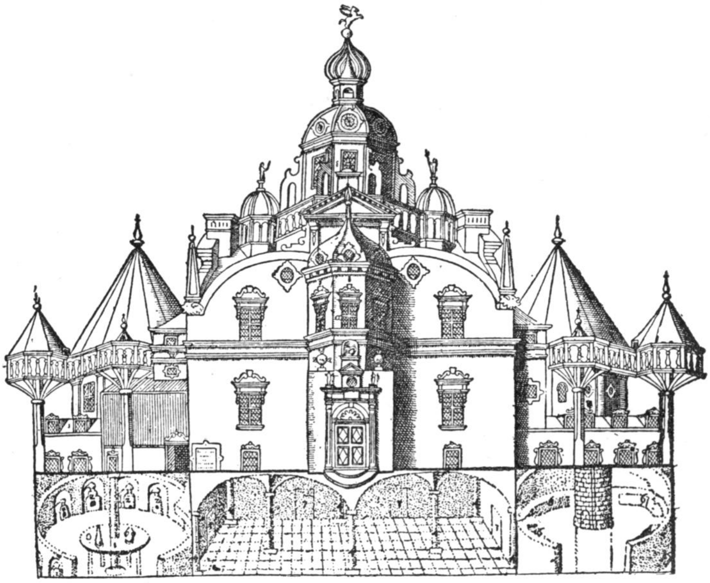
* At the end of this series of articles a list of reference works will be given. It is only just to say here, however, that two of the cuts here reproduced and much of the material for this article were taken from J. L. E. DREYER'S most excellent work, "Tycho Brahe." The other two cuts are taken from "Pioneers of Science," by OLIVER LODGE.



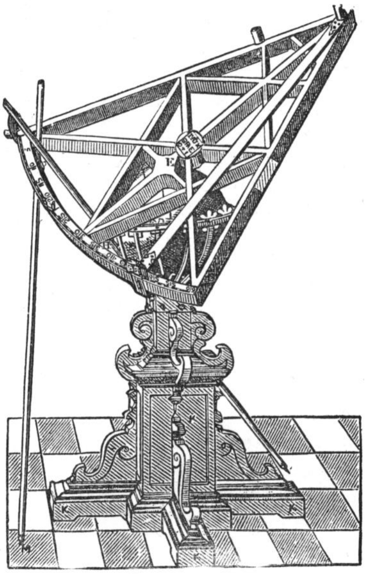
URANIABORG.

hesitancy (it was then considered beneath the dignity of a nobleman to publish books) and considerable urging by his friends, he consented to allow the manuscript to be published. The title is a long and imposing one, and only a few copies of the book now exist. It was afterwards republished in his work, *Astronomiæ Instauratæ Progymnasmata.*

After giving his observations and conclusions, TYCHO goes on to treat of the astrological aspects of the new star phenomenon. Although an interesting subject, and although intimately connected with the astronomy of that date, still I shall not enter into that phase of the subject now.

The foundation-stone of Uraniaborg was laid, with appropriate ceremonies, on the 8th of August, 1576. The building was of the Gothic-Renaissance style, and something of the general plan may be seen from the cut here reproduced. Later (1584) a second observatory, Stjernborg, was erected a short distance from Uraniaborg. In this the observing-rooms were underground, to protect the instruments from the wind.

In all there were twenty-eight instruments in the two observatories. The instruments most used were quadrants, sextants, and armillæ spheres. The first two types have already been described. Quadrants were used by the ancients, although TYCHO attached horizontal circles to some of his with which to measure azimuths. TYCHO supposed himself to be the inventor of the sextant; but the instrument is said to have been used many hundred years before by the Arabs. TYCHO had several of these instruments; some of them were quite large, one having a radius of five and one halt feet. Of course, they were mounted upon stands.

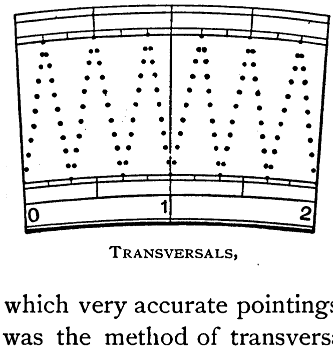

SEXTANT.

The armillæ were of two types, the ancient zodiacal armillæ, for measuring latitudes and longitudes, and the equatorial armillæ.

Instruments of the former type were but little used by TYCHO, but those of the latter type were among his principal instruments. One consisted of three circles of steel, meridian and equator firmly fixed together, and a movable declination-circle. Movable sights were placed on the equatorial and declination circles, while an object-sight was fixed on the polar axis at the center of the sphere. It is easy to see how the declination and hour-angle of a body could be measured with this instrument. Another, considered by TYCHO as one of his most accurate instruments, consisted of a declination-circle nine and one half feet in diameter and a semicircle representing the position of the equator below the horizon. It was provided with appropriate sights, and the polar axis could be adjusted in inclination and azimuth, by means of screws.

Besides these chief instruments, there were many minor ones, such as globes, cross-staffs, and one of historic interest, a triquetrum, made and used by COPERNICUS. With three exceptions, all the instruments were made under TYCHO'S direction in the workshop on the island. The most skilled workmen were employed and the greatest of care was used in the construction of the instruments.

It was, however, not alone the excellence of the instruments that enabled TYCHO and his assistants to make observations so vastly superior to any previously made. Two devices on the instruments added greatly to the accuracy attainable. The devices aided in sighting upon the object and in reading the circle. Before TYCHO'S time it was customary to attach a pinule, with a small hole in it, to each end of the alidade and to sight through these holes. If the hole were small faint objects could not be seen, while if the hole were large the errors of setting were large. TYCHO substituted for holes a system of adjustable slits, by which very accurate pointings could be made. The other device was the method of transversals, which aided in reading the circles. Although not original with TYCHO, still he was the first to make extensive use of this method. The arc was divided upon both the outer and inner circumferences. The transverse line from



TRANSVERSALS,

the end of an outer division to the end of the next following inner division was divided into, say, ten equal parts, and so on. We at once see that if the circle were divided to ten minutes, it could thus be read directly to minutes. These two devices enabled TYCHO to make observations several times more accurate than any previously made. Several clocks were also among the instruments at Uraniaborg, but as they were not very good ones, they were used but little.

The work of the great astronomer at Hveen soon became known, and many students came from all parts of Europe to act as assistants in the observatory. Many observations were made by them. The observations, of course, were all of one kind — observations of position. The Sun, Moon, planets, and comets were systematically observed, and a catalogue of nearly a thousand stars was made.

The observations of the Sun consisted chiefly in taking his meridian altitude with several different instruments. The equinoxes of 1584–88 were observed and the time of arrival of the Sun at points 45° from the equinoxes. From these data TYCHO deduced anew the longitude of the apogee, its annual motion, the eccentricity of the solar orbit, and the greatest equation of the center. Solar tables were also constructed, which were found to be much more accurate than either the Alphonsine or Prutenic tables. The length of the tropical year was deduced by comparing TYCHO'S observations with those of WALTHER, made at Nuremburg, and a value about one second too small obtained.

During early years TYCHO paid but little attention to the Moon. Later, however, systematic observations were made of this body, and several inequalities in longitude and latitude discovered; a more accurate determination of the inclination of the lunar orbit was also made, and the non-uniform retrogression of the nodes was found. Lunar and solar eclipses were regularly observed.

The planets were especially observed by TYCHO from his youth to the end of his career. A great mass of material was accumulated, but TYCHO did not live to deduce the results from these observations. From the standpoint of the advancement of science, it is perhaps not to be regretted that the working up of the observations was left to another. TYCHO certainly would have used his observations to try and prove the truth of his false theory of the solar system; while in the hands of KEPLER, a believer in the Copernican system, they were made to bring forth those three famous laws, and to place before the world the true system of the Sun and planets.

Seven comets appeared during TYCHO'S career, the most brilliant of them appearing in 1577. TYCHO'S observations of these bodies were similar to those made by him upon the new star in 1572. These observations showed that comets possess no parallax measurable with the instruments then in use, thus removing them far beyond the confines of the Earth's atmosphere, where they had been placed by the philosophy of ARISTOTLE. This perhaps is not one of the least of TYCHO'S contributions to science.

TYCHO'S early observations of comets and the new star of 1572 showed him the necessity of more accurate positions of the fixed stars, and he therefore set about compiling a new catalogue of stars as soon as possible after the completion of his observatory. No catalogue of stars had been published since the time of PTOLEMY, and his was probably mainly a reproduction of the still older one compiled by HIPPARCHUS. In determining the longitude of a star HIPPARCHUS used the Moon as a stepping-stone from the Sun to the star; but TYCHO adopted the method of WALTHER, of using *Venus* instead of the Moon, on account of her smaller parallax, slower motion, and smaller diameter.

In 1582, *Venus* was so situated that she could be observed in full daylight for several weeks, and her distance from the Sun could then be measured at a time when both bodies were sufficiently far from the horizon to make errors of the adopted refractions small. The distance between the Sun and *Venus* was measured with a sextant, and at the same time their Declinations were taken with armillæ. These data give the three sides of a spherical triangle, the solution of which gives the angle at the pole between the hour-circles of the two bodies or the difference of their Right Ascensions. The Right Ascension of the Sun being taken from the tables, that of *Venus* becomes directly known. Often altitudes and azimuths of the bodies were taken also. After sunset the same program was carried out between *Venus* and some bright star near the Zodiac, thus giving the Right Ascension of the star, provided the motion of *Venus* between the two sets of observations is taken into account. The Declination was measured directly. In this way the Right Ascensions of several stars around the Zodiac were determined. Each of these stars was then connected by distance measures with α *Arietes*, each thus giving an independent determination of the Right Ascension of that body. This program was repeated on several different years, both when *Venus* was east and west of the Sun. In all, fifteen determinations of the Right Ascension of α *Arietes* were made, and agreed remarkably well among themselves. α *Arietes* thus became the fundamental star of the system, and the Right Ascensions of other stars were determined directly or indirectly from it by distance measures and the solution of spherical triangles. In this way a catalogue of nearly eight hundred stars was made. This catalogue was printed in his work, *Progymnasmata*, and reprinted by KEPLER in the *Tabulæ Rudolphinæ*, in 1627, and by BAILY in "Memoirs Royal Astronomical Society," (Vol. XIII.)

Another important contribution to practical astronomy was TYCHO'S investigations upon the subject of asmospheric refraction. The phenomenon of refraction was discovered by PTOLEMY in the second century of the Christian era, but no observer before TYCHO ever constructed a table of refractions or corrected observations for this source of error. TYCHO constructed a table of refractions for different altitudes by taking the difference between observed and computed altitudes of the Sun. A similar table was constructed in the same way for the fixed stars, but there was considerable of a difference between the two tables, due to the fact that in reducing the observations of the Sun an erroneous value of the solar parallax (3′) was used. This is the only astronomical constant that TYCHO took from his predecessors, and it was perhaps more widely wrong than any other. It seems strange that he should never have suspected that the difference between the solar and stellar refractions was due to this cause.

But little was accomplished by TYCHO after leaving Denmark. A portion of the instruments were set up near Prague, but few observations were taken with them. After TYCHO'S death they were purchased by the Emperor, stored in a cellar, and all save the great globe were destroyed in the rebellion of 1619. The globe, after many wanderings, was finally taken to Copenhagen and unfortunately destroyed in the great fire of 1728. There now remains, as far as known, no vestige whatever of TYCHO'S celebrated instruments. The observatory at Hveen was soon allowed to decay after TYCHO'S departure, and now nothing remains but a mound of earth to mark the spot where this temple of science once stood.

Many of TYCHO'S manuscript observations are now deposited in the Royal Library in Copenhagen. His principal published books have already been mentioned. *Astronomiæ Instauratæ Mechanica*, an illustrated description of the principal instruments of the observatories at Hveen was issued in 1598. A reprint was issued in 1602. The other work, *Astronomiæ Instauratæ Progymnasmata;* or, Introduction to the New Astronomy, was only printed in part before TYCHO'S death. It was designed in this to give all of his investigations which led up to an exposition of his theory of the solar system and to the construction of planetary tables. The first volume related to the new star of 1572; the second volume to the comet of 1577. Other volumes were to treat of precession, refraction, motion of Sun, lunar theory, etc. Some of these were later printed by KEPLER.

We have thus given in brief an account of the principal achievements of TYCHO BRAHE. I have dwelt upon them because they mark the beginning of modern practical astronomy. TYCHO'S methods were thoroughly scientific, the advance over the work of all predecessors was great, and it was there on that little island in the sea that the firm foundation was laid.

TYCHO must have been a man of great energy. A great mass of observations was accumulated by him; but, of course, we must not overlook the fact that he had many assistants who took part in the observations. It is not, however, so much the quantity as the quality of the observations that calls for our admiration. Indeed, when we consider the fact that he had neither telescope nor vernier, we sometimes marvel at the accuracy attained in the observations.

Eminently successful as a practical astronomer, TYCHO did not attain eminence in a theoretical line. He could accept neither the Copernican nor the Ptolemaic theory of the solar system, but constructed a compromise between the two. Perhaps little need be said of this theory. It made but few converts and fortunately died with its originator. Nevertheless the life work of TYCHO is certainly not less eminent, but perhaps more eminent, than that of COPERNICUS, for it is certain that KEPLER could not have worked out the true system of the universe without TYCHO'S observations; whereas, he might have done so had the theory of COPERNICUS never been promulgated. Still the works of each were great, and perhaps too unlike to be compared; not more unlike, however, than the men themselves. "COPERNICUS was of humble origin, and certainly not wealthy; TYCHO BRAHE was of noble birth, and inherited great riches. COPERNICUS loved solitude and rest; TYCHO BRAHE restlessly moved from place to place all over Europe. COPERNICUS was calm and peaceful in disposition; TYCHO BRAHE was a man of violent temper. COPERNICUS was always tender to the prejudices of others; TYCHO BRAHE delighted in attacking false beliefs. They resembled each other in one point alone — the patient carefulness of their researches, and the strenuous earnestness of their lives."

(To be continued.)

PHOTOGRAPHIC OBSERVATIONS OF COMET *a* 1899 (SWIFT).

By E. F. CODDINGTON AND H. K. PALMER.

At the time of its discovery this comet was too near the Sun to be photographed. But after it had passed perihelion it became a morning object, and its apparent distance from the Sun rapidly increased. It was then photographed with two instruments at the Lick Observatory, on every suitable night from May 6 to June 13, 1899, inclusive. In all, thirty negatives were obtained. Of these, nine were taken by Mr. CODDINGTON with the Crocker photographic telescope, and twenty-one by Mr. PALMER with a 6-inch Willard lens strapped to the 5-inch Floyd telescope. The Crocker telescope is provided with a 6-inch Willard lens having an equivalent focal length of 30.82 inches. The scale of the negatives obtained with this lens is therefore as follows: 1 degree = 0.538 inch; or, 1 inch = 1.86 degrees. The lens used by Mr. PALMER has an equivalent focal length of 25.99 inches, making the scale of his negatives as follows: 1 degree = 0.454 inch; or, 1 inch = 2.20 degrees. The reproductions all have the same scale as the original negatives.

Unfortunately, owing to the close proximity of the comet to the Sun at first, and later to the pressure of other work, it was impossible to obtain a series of exposures of uniform length. Two exposures were made with each instrument on the first night to determine if possible any evidences of rapid changes in the struc-